TARDEC ACTIVE PROTECTION SYSTEM COMPLIANCE PLAN (U)

S. Durbin, N. Fountain, W. Norton
U.S. Army Tank-Automotive Research, Development, and Engineering Center
Warren, MI 48397-5000

ABSTRACT (U)

(U) Active Protection Systems (APS) have been in the design and development stages since the early 1950s, but none have successfully made the transition from development to integration on a platform. A contributing factor of this lengthy development period is the lack of common standards, APS requirements or a fielded system that can be followed as a template. Although lacking firm APS requirements, an APS should be developed for and tested in a relevant environment that mirrors the operational environment of its intended host vehicle. Since APS is a new technology, there has been no logical process to follow. The Tank Automotive Research Development and Engineering Center (TARDEC) has developed an APS Compliance Plan to serve as a developmental roadmap and a TRL estimation tool. Using this plan one may determine specific tasks or tests necessary to advance to a higher TRL, as well as assess the risk involved with transitioning an APS at its current technology state. Further, TARDEC will use a configuration management process to increase the likelihood of APS transition to a program of record. This paper will introduce the TARDEC APS Compliance Plan and describe how it can be used focus APS development and transition. TARDEC plans to assist development and transition minded efforts with a System Integration Laboratory (SIL) validation process as well as present the vision for how the Compliance Plan will operate in the future.

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14. ABSTRACT
Active Protection Systems (APS) have been in the design and development stages since the early 1950s, but none have successfully made the transition from development to integration on a platform. A contributing factor of this lengthy development period is the lack of common standards, APS requirements or a fielded system that can be followed as a template. Although lacking firm APS requirements, an APS should be developed for and tested in a relevant environment that mirrors the operational environment of its intended host vehicle. Since APS is a new technology, there has been no logical process to follow. The Tank Automotive Research Development and Engineering Center (TARDEC) has developed an APS Compliance Plan to serve as a developmental roadmap and a TRL estimation tool. Using this plan one may determine specific tasks or tests necessary to advance to a higher TRL, as well as assess the risk involved with transitioning an APS at its current technology state. Further, TARDEC will use a configuration management process to increase the likelihood of APS transition to a program of record. This paper will introduce the TARDEC APS Compliance Plan and describe how it can be used focus APS development and transition. TARDEC plans to assist development and transition minded efforts with a System Integration Laboratory (SIL) validation process as well as present the vision for how the Compliance Plan will operate in the future.

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(U) History of Active Protection

(U) An Active Protection System (APS) is specifically designed to prevent direct fired threats from acquiring and/or destroying a target. An APS is either a softkill or hardkill system based on its method of defeating a threat. The countermeasure of a softkill APS alters the electromagnetic or acoustic signature of a target which effectively alters the tracking and sensing capability of the incoming threat; a hardkill APS physically counterattacks the incoming threat by destroying the warhead in such a way that the intended effect on the target is majorly impeded—both defeat methods have proven their effectiveness for neutralizing incoming threats.

(U) Primitive APS were being developed in the early 1950s, beginning with the Army Research Laboratory's Dash-Dot Program (shown in Figure 1) and eventually evolving into more recent designs (Atlas, TRAPS, Iron Curtain, EPS, etc.). All APS have struggled with the transition from their development to the final integration onto a platform for fielding.

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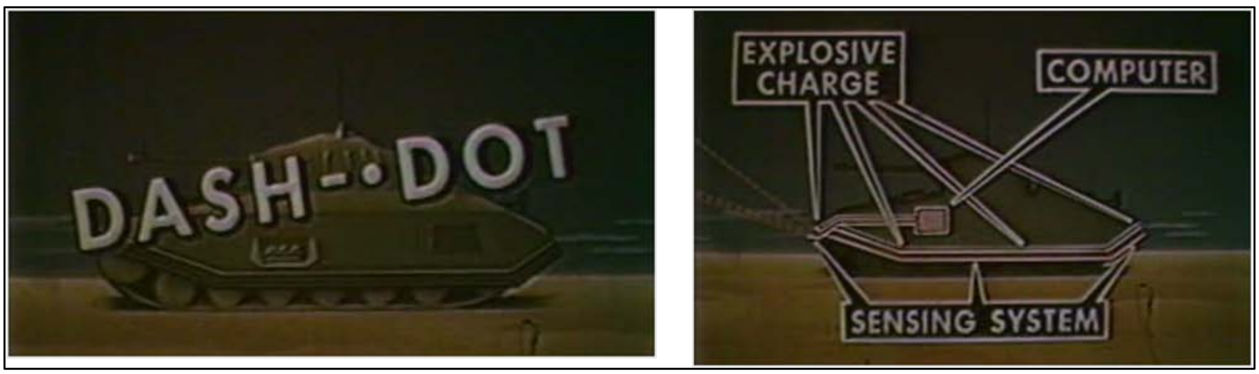

Figure 1. (U) Primitive Active Protection Systems

(U) Current Situation

(U) Throughout the history of APS, none have successfully transitioned from development to integration on a platform to be fielded by the Department of Defense (DoD). To date no APS has been proven to be ready for fielding in regard to their consistent capability to defeat incoming threats and to do so in a relevant environment. The accepted maturity level for new technologies to transition to a PM for final development and integration onto a host platform is TRL 6. The TRA Deskbook defines a relevant environment as representative of the full spectrum of the intended operational environments[1]. Since an APS is intended to be integrated to a tactical or combat vehicle, the implied relevant environment for any APS should be that of its intended host vehicle. For example, a lightweight, low cost APS developed to defeat Rocket Propelled Grenades (RPG) intended for transition on a tactical vehicle, which is a relatively light weight, low cost platform and prey to RPGs. Similarly, a more capable but heavier and higher cost APS capable of defeating Anti-Tank Guided Missiles (ATGM) would be intended for an armored combat vehicle. The APS Compliance Plan aims to function as a link between establishing TRL guidelines for enabling technologies and a smooth transition to a program of record managed by the TRA Deskbook.

(U) One major reason the gap between development and transition exists is the discrepancy between the APS design intent and the Program Manager requirements. In order to increase the potential for transition, the contractor should be concentrating on the relevant environment as implied by the PM requirements for their platforms during the early stages of design and development. Before a PM would likely accept an APS for transition, it must be: (1) at a TRL 6 or higher, (2) require no major redesign activity and (3) be a well understood system.

(U) TRLs provide a common understanding of technology maturation and can be used as a risk management tool. The APS Compliance Plan concentrates specifically on TRLs 4 through 6 in an effort to mature the APS technology so it is production ready. TRL definitions are shown in Figure 2. PM offices generally do not transition an APS if it is below the TRL 6 threshold.

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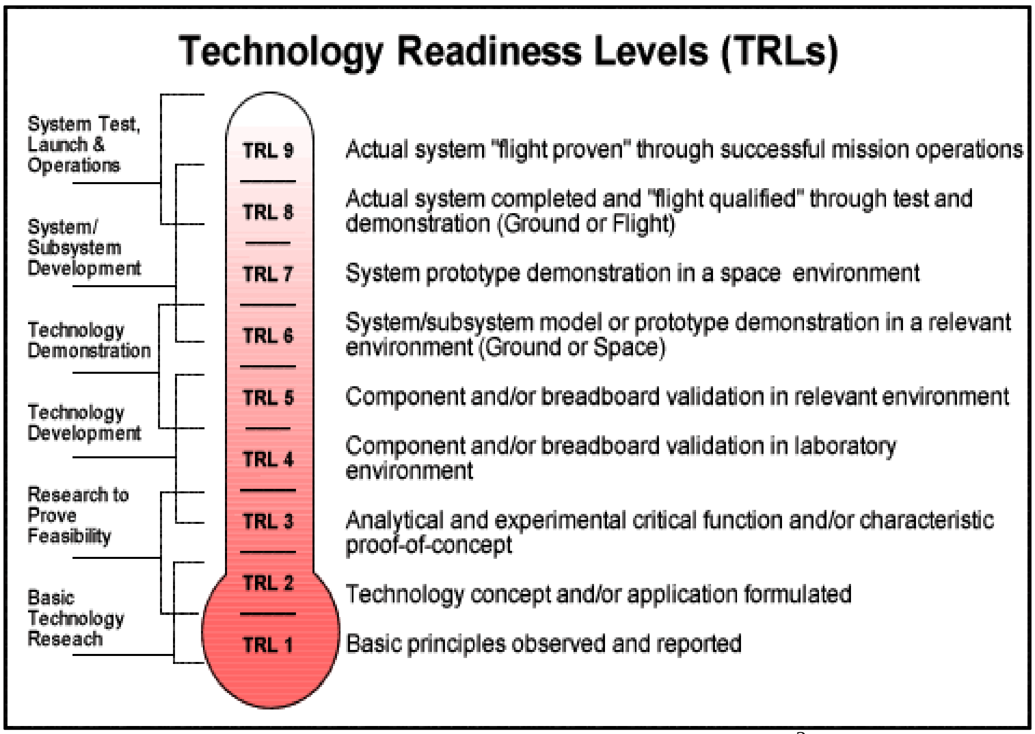

Figure 2. (U) Technology Readiness Levels[2]

(U) PMs want to mature existing technologies as opposed to developing new APS technologies. They will look to integrate a production ready APS that requires no major redesign activity after transition. The hardware and software should have a locked configuration that is specific to the target platform. Post technology transition, minimal research and development funding will exist. The PM cannot afford any major redesign setbacks after transition, if they strive to meet program schedule and cost.

(U) The PM will aim to transition a well understood system onto their platform. Performance statistics are essential. The system should be tested against live threats prior to transition with data supporting the claimed probability of defeat (P_{Defeat}). System vulnerabilities should be well understood. An acceptable performance risk threshold will always exist; however, mitigation plans should be in place to improve any areas with inferior performance. A PM can always transition a system with a greater performance risk, if there is an urgent need for additional protection. The Compliance Plan is not a mandated activity but rather a risk assessment tool that focuses development.

(U) Compliance Plan Overview

(U) In an effort to narrow the gap between APS development and what a PM desires for transition onto a platform, TARDEC has developed an APS Compliance Plan. The primary objectives of the Compliance Plan are to:

(U) (1) estimate the TRL of a specific APS to a common standard;
(U) (2) verify TRL compliance to Program Managers interested in APS transition;
(U) (3) determine if the APS is mature enough to start a compliance effort;
(U) (4) establish specific tasks required to achieve each TRL milestone with respect to APS technologies as a function of gate review.

(U) It is essential that the TRL of each APS is evaluated using a common standard to avoid discrepancies between the system capability and the PM requirements for competing technologies. The Compliance Plan will be tailored to a particular APS with platform specific requirements in mind. As a contractor is developing an APS technology, the Compliance Plan can serve as a roadmap to ensure they are working toward a transition ready system. All contractors can utilize the same roadmap, essentially leveling the playing field for all APS developers.

(U) The PM needs a method to verify that the claimed TRL of the APS is an appropriate assessment. A PM, after receiving a proposal for transition, can turn to TARDEC to verify the TRL of that particular APS. TARDEC engineers can work collaboratively with the contractors, while utilizing the Compliance Plan, to make an unbiased and accurate TRL assessment of the system. This third-party TRL assessment can (1) prove invaluable for risk reduction and (2) hold more weight with the PMs interested in transition.

(U) A significant DoD investment will be required each time the Compliance Plan is executed. The Compliance Plan is a lengthy process that will require funding; both PMs and TARDEC need to be selective when determining whether an APS is ready to apply for Compliance. Prior to starting a Compliance Plan effort, TARDEC must verify that both hardware and software configurations are locked as any configuration or design change will end the effort and require a new Compliance Plan assessment in the future.

(U) As previously stated, each Compliance Plan effort will be APS specific. The tasks and testing required for each APS will be established at the beginning of each Compliance Plan effort. Each APS will have a tailored set of tasks and tests that, upon successful completion, will put the APS in the best possible position for transition. The Compliance Plan will utilize TARDEC's new gate review process called TARGET (shown in Figure 3) to ensure the key tasks required are aligned appropriately with customer needs.

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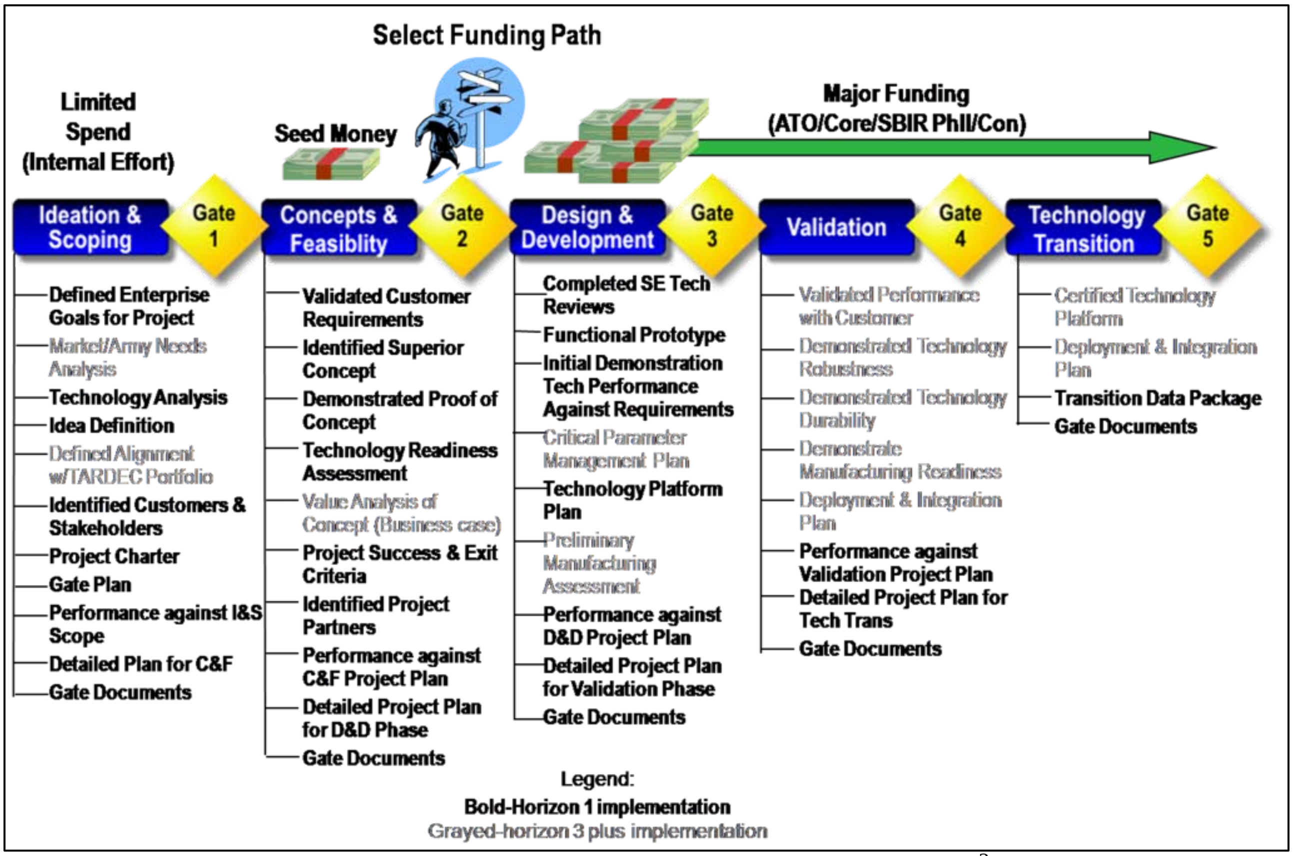

Figure 3. (U) TARDEC TARGET Gate Review Process[3]

(U) The APS Compliance Plan uses specific requirements to measure and evaluate the technical maturity of APS, subsystems, components and software configurations. The Compliance Plan concentrates on TRL 4 through 6 tasks, working from the design intent of the components/system (TRL 4), component testing and validation (TRL 5) and system demonstration in a relevant environment (TRL 6).

(U) Compliance Plan Attributes

(U) The Compliance Plan is intended to be a risk assessment tool for PMs. They determine the allowable risk tolerance and can transition any APS configuration at any time. The Compliance Plan is a detailed process to determine technical maturity of an APS. Tasks and tests are broken down to fundamental levels to ensure that the performance of each component is both verified and validated. The Plan is a comprehensive effort including all government activities required to assure the APS works as intended and that it meets the transition requirements. It is also a living document that will be customized for each APS technology Compliance effort and configuration managed as well.

(U) APS Compliance is not intended to be a research and development effort, rather the validation of one. Prior to entering a Compliance Plan assessment, the APS must be both software and hardware configuration locked and require no major design changes. Upon receiving APS Compliance, the contractor is not guaranteed transition to a program of record; however it may increase the possibility of one. The TRL assessment and conclusions will be provided to the PM, who has final decision authority for transition.

(U) Program Structure

(U) A detailed layout of the APS Compliance Program Structure is shown in Figure 4. This figure demonstrates how the APS Compliance Plan will fit into the TARDEC TARGET gate review process as well as how it could feed into an acquisition program of record. Generally, prior to entering a Compliance effort, the APS should have received a successful Gate 3 review. All major design and development stages should be complete and both the hardware and software should be configuration locked; however, this is a gray area. If the majority of the design process is complete, a PM could request that it enter a Compliance effort early, with a greater risk for not reaching the objective TRL Compliance at the completion of Gate 5. Minimal research and development funding will be available; it is in the contractor's best interest to be as far along in the design process as possible before starting a Compliance effort.

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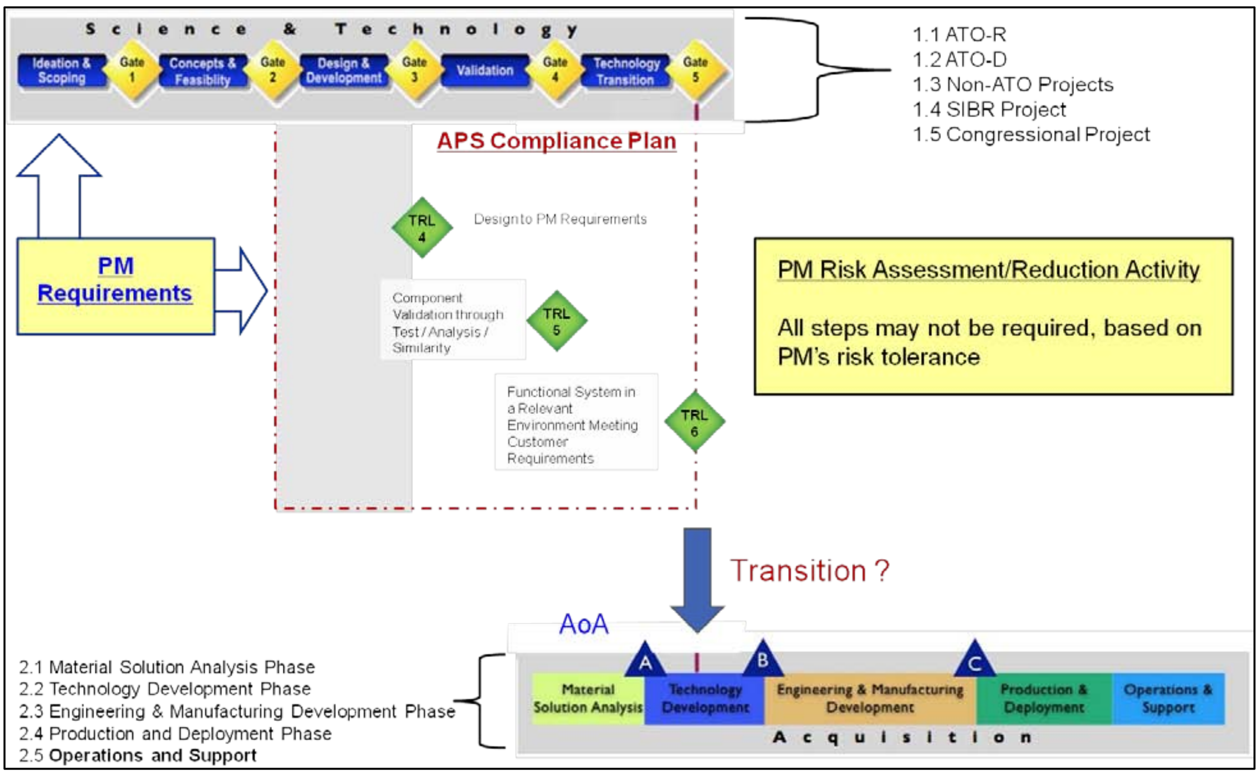

Figure 4. (U) APS Compliance Plan Program Structure

(U) This program structure layout assumes that there are well defined PM requirements in the beginning concept, feasibility and design phases. The requirements should be in place after a successful Gate 1 review, but are subject to change once the design process has begun. These changes may be necessary because there will be a better understanding of how the APS will operate; this could lead to unforeseen requirements that must be met before the PM will consider transition. Any requirement change will end the current Compliance effort. Another effort may start in the future, once the new or modified requirements have been addressed.

(U) An important note is that all Compliance Plan steps may not be required based on the PM's risk tolerance. If the PM has an urgent need, he could accept additional risk and bypass some steps in the Compliance Plan process on his way to transition. This, although possible, will more than likely not be a common practice. A successful Gate 5 review implies that the APS has been granted a TRL 6. At this point the PM has the option to transition the APS into a program of record. By no means does achieving a TRL 6 or APS Compliance guarantee transition onto a platform; final transition authority lies with the PM.

(U) Configuration Management

(U) Each Compliance Plan effort is tailored to a specific APS hardware and software configuration. At the beginning of the effort, TARDEC and the PM will determine applicable tasks and tests for each TRL milestone. Once the TRL assessment process has started, any configuration or design change will require a new Compliance Plan effort. It is possible to have different configurations—either software or hardware—at different TRLs. PMs reserve the right to transition any configuration at any time, depending on urgent needs and their risk tolerance for the potential capability.

(U) During an APS assessment, if configuration or design changes are deemed necessary, a new Compliance Plan request must be submitted. For example, changes in the processor software may affect the sensor performance; as a result, all elements of the Compliance Plan assessment must be reevaluated. Any requirement, configuration or design changes results in the termination of the current Compliance effort. During the subsequent Compliance Plan efforts, elements may be accepted based on similarity to previous configurations or designs, but those decisions will be made at each review or submission.

(U) Figure 5 shows an example configuration management flowchart for an APS Compliance effort. While TARDEC works the Compliance effort of Configuration C, a PM could transition or start a program of record for either Configuration A or B, depending on urgent mission requirements or an acceptable performance risk tolerance. The PM acknowledges that transitioning an earlier configuration may have degraded safety or performance.

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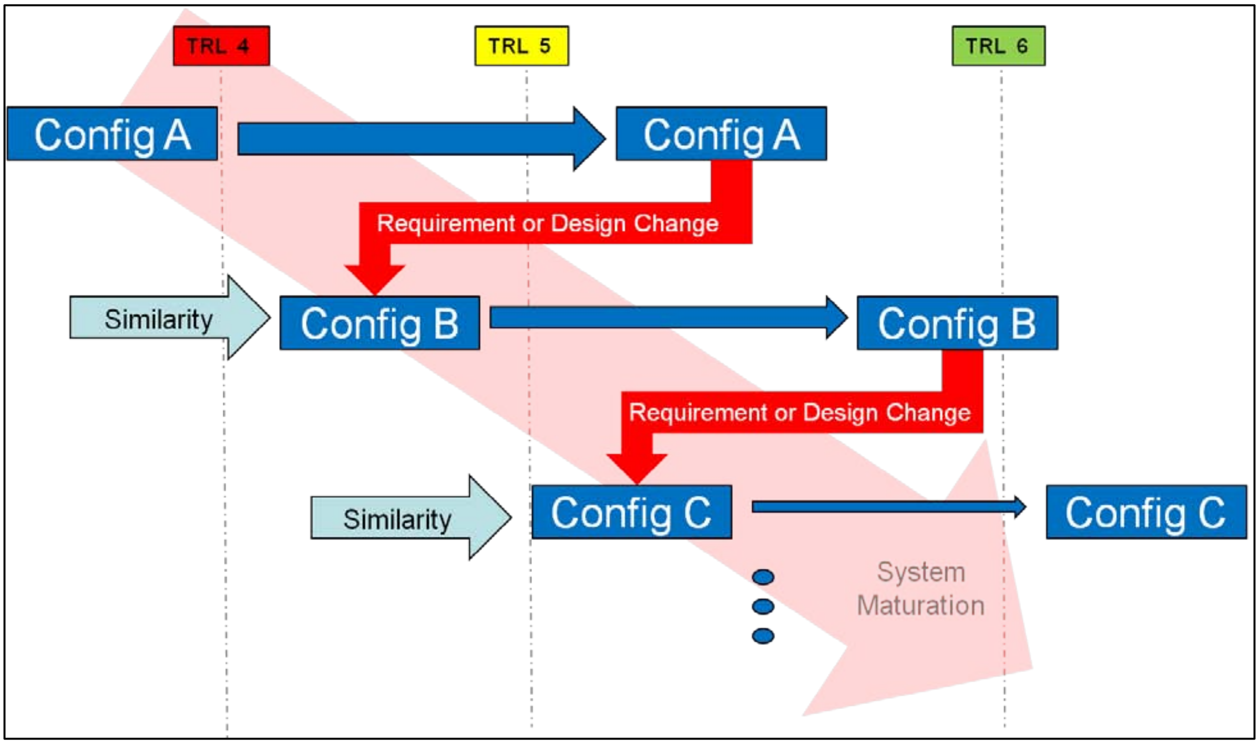

Figure 5. (U) APS Compliance Plan Configuration Management

(U) <u>Decision Process</u>

(U) An example of an APS Compliance Plan decision process is shown in Figure 6. The decision process shows example tasks and how the TARGET gate review described above fits into the APS Compliance Plan. Each gate roughly translates to a TRL threshold. The red arrows show the effect of a requirement, configuration or design change; they demonstrate the system maturation process. Theoretically, each subsequent Compliance Plan effort will improve upon the previous effort. If an APS has a successful Gate 5 review, it reaches a major decision point. It is at this point where the APS is assigned the appropriate TRL for the effort and granted compliance (Typically targets 6). If an APS completes the Compliance Plan, it is not guaranteed that it will be granted compliance status or transition to a program of record.

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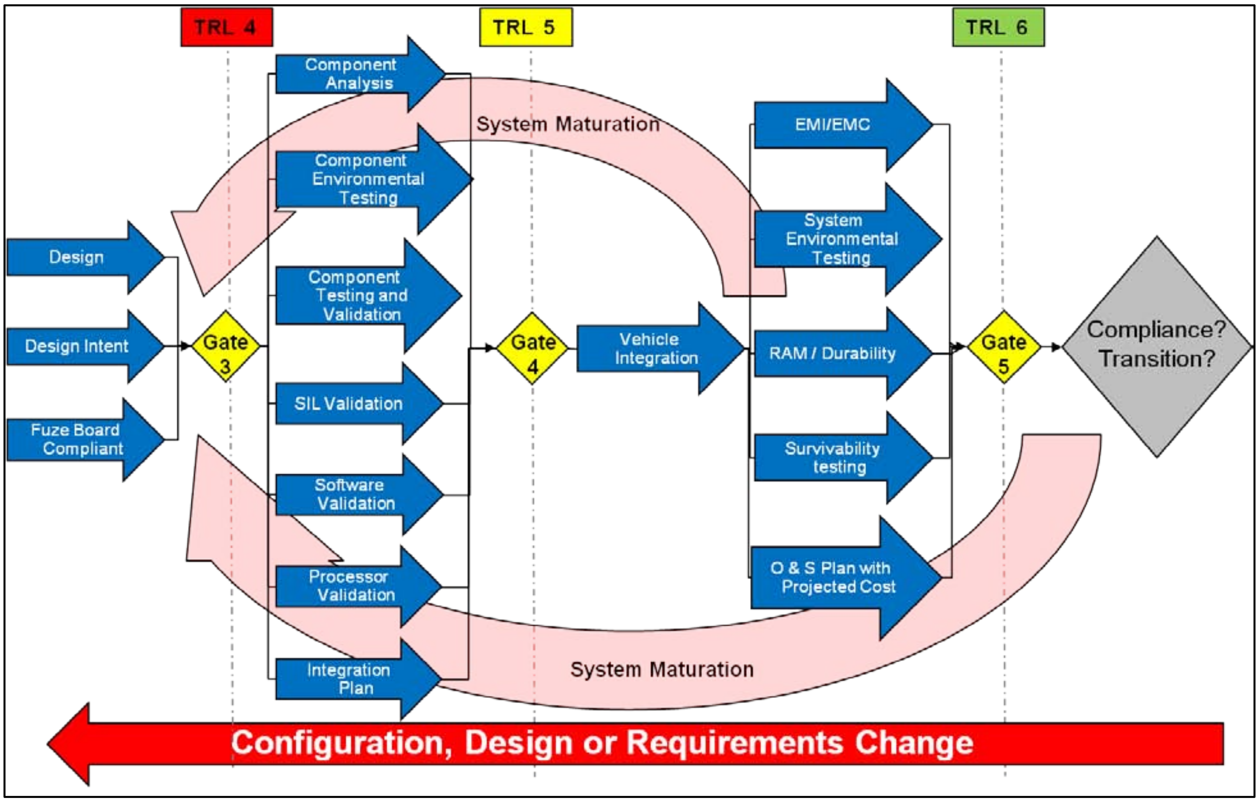

Figure 6. (U) APS Compliance Plan Decision Process

(U) The APS Compliance Plan concentrates primarily on verifying TRL 4 through 6 tests. Prior to attaining TRL 4 (Gate 3 review) the design intent is taken into account. Similarly, before reaching TRL 5 (Gate 4 review) all necessary component-level testing in a relevant environment as well as SIL unit testing must be successfully completed. At the TRL 6 milestone (Gate 5 review) the system should have a successful prototype demonstration in a relevant environment and successful completion of SIL integration testing. At this point, the system should be mature enough for a PM to transition the APS onto the target platform.

(U) During the early conceptual and development stages it is essential to design for the relevant environment as well as the platform and Army Fuze Safety Board requirements. If a PM needs an APS that will work in extreme weather conditions of -40 to 120°C it would not make sense to design a system for operating in the temperature range of -10° to 100°C. Not meeting the platform requirements is an easy non-starter for PMs. Similarly, the APS must be Fuze Board compliant prior to transition onto a platform. Understanding the Fuze Board requirements and designing to them at an early conceptual stage can make a big difference for an APS looking for transition. PM support is required for a letter of compliance, and if its support is not given for a particular compliance plan, the assessment will be made with existing guidelines and given a higher risk potential.

(U) The APS Compliance Plan crawl, walk, run strategy is shown in Table 1. The table provides a visual representation of how each TRL builds on the previous TRL. TRL 4 primarily deals with design intent and early stage conceptual and developmental testing. At the next level, individual components should be designed and SIL validation and verification begins. Once each component has been successfully tested in the relevant environment, APS system integration, system level testing and prototype demonstration can begin.

Table 1. (U) APS Compliance Plan Crawl, Walk, Run Strategy

GATE 3 / TRL 4 Design Intent	GATE 4 / TRL 5 Component-Level	GATE 5 / TRL 6 System-Level
Relevant Environment	Component Analysis	Full System Demonstration
Platform Requirements	Test Plan Outlines	Integration on Platform
Fuze Board Compliance	Component Testing in Relevant Environment	Operations & Support Plan with Projected Costs
Production Readiness	SIL Validation	
Prototype Cost Estimates		

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(U) At any point if the Compliance Plan effort fails to meet a requirement or changes to the design or configuration (software or hardware) are needed, the assessment is ended. Once the necessary changes have been addressed, another assessment based on the revised configuration may be undertaken, if the resources and support required are available. Certain component tests may still be considered acceptable based upon similarity to previous configurations or designs, if deemed appropriate by TARDEC. However, each component will be readdressed.

(U) Together the Compliance Plan assessments for an APS will go through a system maturation or optimization process. Each effort could find minor design flaws or software bugs that require a redesign of the system or a component. An advantage of the Compliance Plan is that these minor issues and bugs can be found early in the development process when the monetary cost of redesigning components or software is significantly lower that when the APS is farther along in the process. Each time these minor issues are fixed, the risk of failures if transitioned onto a platform is considerably decreased.

(U) A major decision point occurs after the APS successfully reaches the Gate 5 review. It is at this point that TARDEC must determine the appropriate TRL of the system and recommend it for compliance. Depending on which tests have been completed successfully, TARDEC also assesses if there is a significant risk if the PM opts to transition the APS. It is possible for TARDEC to determine that the risk is too high, implying the APS may not reach its objective TRL Compliance. Similarly, if the APS reaches TRL 6, it is not guaranteed transition to a program of record. This decision is ultimately left to the PM; however receiving TARDEC compliance will increase the chance of being selected for transition onto a platform.

(U) <u>SIL Validation</u>

(U) While completing a Compliance Plan effort, TARDEC plans to perform in-house SIL validation testing on the APS and the individual components. SIL validation is a disciplined process to evaluate the behavior, performance and robustness of both a system and its components. The expected behavior, performance and robustness of the system and components should be formally described and measured prior to the validation process. This would include factors such as functionality, logical correctness of the component/system and timing constraints. More specifically, TARDEC will determine if the APS functions, if it operates as expected and if it operates fast enough.

(U) Validation of a component or system will:

(1) determine that the engineering design and development process is complete and meets specifications;
(2) minimize design risks;
(3) determine if the design is supportable, practical and maintainable;
(4) evaluate tradeoffs against specification requirements.

(U) Detailed reports of observation will be recorded for each stage of SIL testing. These will help determine the test's pass and failure metrics. A failure may be due to a nonconformance to the requirements; there has been an error in conducting the test (resulting in a 'no-test'); or that the implementation cannot be executed. The TARDEC SIL validation process will be used to validate both software and hardware components prior to the system as a whole. Specifically, TARDEC will concentrate on SIL unit testing, SIL integration testing and SIL validation testing.

(U) SIL unit testing is the verification and validation method used to exercise the features of individual components when they are isolated from other components of the system. The first step of unit testing is to define the individual test cases or components. A detailed breakdown of the APS is required to determine what parts of the system are considered individual components. Components are defined as a piece of application that has its own thread of control.

(U) There are two general approaches to accomplish SIL unit testing. The first of which is to apply all possible use cases as found in the requirements. This is typically difficult, if not impossible, to accomplish on a complex APS. The second approach is to apply a large range of data variation for function parameter value; this is less robust than the first method, but is significantly more reasonable.

(U) In order to successfully accomplish SIL unit testing, the test engineer must be familiar with the content of the unit being tested. Finding and eliminated bugs at the component level will prevent difficult tracking of trivial errors in the complex system level testing that occurs later in the SIL validation process. The higher the level of testing, typically the more difficult it is to isolate individual bugs. The goal is to find as many bugs as possible during SIL unit testing, to make the integration and system level validation testing easier.

(U) SIL unit testing can be broken into two general categories: functional tests and requirements verification. In a functional test, the test engineer is concentrating on whether the components function at all. Here, the goal is to verify that the component is stable, does not crash unexpectedly and sends/receives messages in the appropriate form. Requirement testing verifies whether the component meets required performance. Here, the goal is to verify the logical correctness and timing constraints of the component.

(U) SIL integration testing evaluates the functionality of a collection of integrated components; validation of the system as a whole. The system at this point is examined by a stand-alone system and is not connected to the 'outside world' that is environmental conditions, etc. Tests are similar to that of unit testing, except at a slightly higher level. Again, the functionality and requirements categories of testing will be used.

(U) SIL validation and system testing, also referred to as Hardware-in-the-Loop (HWIL) testing, is the equivalent of a high level integration test. Components have been integrated into a system and tested at the previous stage. At this point the system is connected to the 'outside world' to evaluate function and performance. An added advantage to performing SIL validation testing in a lab environment as opposed to field testing is the monetary and potential schedule savings.

(U) Future Plans

(U) The APS Compliance Plan will utilize the TARDEC Advanced Collaborative Environment (ACE) for all future Compliance Plan efforts. Users will have access to any applicable reference documents, current APS requirements as well as an up-to-date version of the tasks and tests required for each TRL milestone. Each contractor will have their own folder that will organize all Compliance Plan documents by configuration. The most recent version of the plan is provided in Appendix A.

(U) Summary

(U) The TARDEC Active Protection System (APS) Compliance Plan attempts to bridge the gap between APS development and integration onto a platform. It is intended to serve as a common standard for all APS developers to follow as a template. A Compliance Plan effort should help the contractors design the APS with the system requirements and the relevant environment in mind. This will help decrease performance and safety risks while increasing the possibility of transition by a Program Manager (PM).

(U) Each Compliance Plan effort will be subject to configuration management to encourage system maturation and focused development of the system. This will increase the possibility of reaching a higher TRL milestone and better prepare the system for transition. All steps in the Compliance process are not mandatory; the PM has final decision authority of which steps need to be completed. At any point during the Compliance effort, the PM may transition any configuration (hardware or software) depending on urgent mission requirements of acceptable performance risk limits.

(U) Upon completion of an APS Compliance effort, the system is not guaranteed compliance status or transition into a program of record. Successful completion will not guarantee transition, although it may increase the possibility of transition. The PM has final decision authority of which configuration to transition and when it will be transitioned onto a platform.

(U) For APS Compliance Plan questions, comments, additional information or instructions for how to access the APS Compliance Plan on ACE please contact: DAMI_TARDEC_GSS_AP.C@conus.army.mil.

(U) References

(U) (1) Director, Research Directorate (DRD) and Office of the Director, Defense Research and Engineering (DDR&E). (2009, July). *Technology Readiness Assessment (TRA) Deskbook.*

(U) (2) Nolte, W., Kennedy, B., Dziegiel, R. (2003, October). *Technology Readiness Level Calculator*. Presented at NDIA Systems Engineering Conference.

(U) (3) *TARGET Technology Development Process.* Retrieved on August 12, 2010, from https://wiki.kc.us.army.mil/wiki/TARGET_Process

(U) Acknowledgements

(U) (1) TARDEC Ground System Survivability KE APS team for assisting with the development of APS Compliance Plan tasks and tests.

(U) (2) TARDEC Systems Engineering, CASSI, HPC, Intelligent Ground Systems teams and AMRDEC Lethality, Network, Protection and Sensor TFTs for reviewing Compliance Plan tasks to capture additional requirements and/or sub-processes.

APPENDIX A
TARDEC APS COMPLIANCE PLAN
VERSION 2.0
Last Updated: 16 AUG 2010

Line	**Task Name**	**TRL** *
1	Gate 1	*
2	Concept and Performance	
3	Proof of Concept Demonstration	TRL 3
4	Preliminary SWAP-C	TRL 3
5	Preliminary Performance (P defeat)	TRL 3
6	Verified Model	TRL 3
7	Timeline Analysis	TRL 3
8	Assumed User Requirements	TRL 3
9	SRR w/ Vendor	TRL 3
10	Functional Baseline (System)	TRL 3
11	Allocated Baseline (Item)	TRL 3
12	Product Baseline (Component)	TRL 3
13	RFI Applicable Documents	TRL 3
14	Equipment Parts list (EPL) / Configuration Parts List (EPL) {Including software build}	TRL 3
15	Bill of Materials (BOM) definition breakdown through purchased COTS & raw material	TRL 3
16	Military and Federal Specifications, Standards, and handbooks used.	TRL 3
17	Interface Control Documentation. This includes all related of referenced Interface control documents and interface control specifications.	TRL 3
18	Other Documentation	
19	Establish Current TRL of the APS	
20	IPR w/ vendor and PM	
21	Assign TARDEC Sponsored APS Build No.	
22	Gate 2	*
23	System Design	TRL 3
24	Verify Design Intent (Relevant Environment)	TRL 3
25	Verify Design Intent (PM Requirements)	TRL 3
26	Functional Prototype	TRL 3
27	Technology Platform Plan	TRL 3
28	Gate 3	*
29	**LRU Functional Block Diagram**	TRL 4
30	**LRU Characteristics and Requirements**	
31	Full Performance Envelope defined (PO, FA, Arena Testing, Defeat Mechanism, etc.)	TRL 4
32	Shake, Rattle, Roll, Specialty Analysis	TRL 4
33	Architecture, Requirements, CM	TRL 4

34	**Insensitive Munitions Tests**	TRL 6
35	Insensitive Munitions Board Approval Letter	TRL 6
36	Fast cook-off	TRL 6
37	Slow cook-off	TRL 6
38	Bullet impact	TRL 6
39	Fragment impact	TRL 6
40	Sympathetic detonation	TRL 6
41	Shaped charge	TRL 6
42	High velocity fragment impact	TRL 6
43	**Counter Measure**	
44	SMALL ARMS Protection (7.62 Ball)	TRL 5
45	Environmental	TRL 5
46	Temperature Envelope	TRL 5
47	Temperature Cycling	TRL 5
48	Sand	TRL 5
49	Humidity	TRL 5
50	Salt Spray	TRL 5
51	Vibration MIL-STD 810	TRL 5
52	Environmental Tests	TRL 5
53	Fly-Out Counter Measure	
54	Countermeasure Sensor (seeker)	TRL 5
55	Range	TRL 5
56	Timing	TRL 5
57	Accuracy	TRL 5
58	**Airframe (SE)**	
59	Safety factors and structural guidance as specified in MIL-M-8856B used for guidance in developing the airframe.	
60	Netting analysis to verify motor case structural design.	
61	Finite element structural analyses to verify airframe integrity for flight testing.	
62	Modal analyses to determine mode shapes and frequencies. Results used to develop body bending transfer functions for design of autopilot. Modal frequencies correlated with telemetry data from flight testing.	
63	Aero-elastic flutter analyses to determine flutter boundaries of airfoil surfaces used for flight stabilization.	
64	Hydro-burst tests of motor case to insure structural integrity.	
65	All airframe motor cases hydro-proofed prior to use in flight testing.	
66	Static motor firings to characterize motor performance, including thrust and pressure loads acting upon airframe.	TRL 4
67	Successful flight of airframe on LTV flights.	TRL 5
68	Successful flight of airframe on BTV flights.	TRL 6
69	Successful flight of airframe on CTV flights.	TRL 6

70	**Propulsion**	
71	**Warhead**	
72	**IMU**	
73	**Inertial laboratory**	
74	Characterization tests confirm IMU performance compliance over temperature from +60 deg C to -40 deg C. Components of a characterization test are:	TRL 6
75	- static noise (gyro angle random walk and accelerometer velocity random walk)	TRL 6
76	- tumble (accelerometer and gyro bias & repeatability, misalignments, and accelerometer scale factor)	TRL 6
77	- integrated angle (gyro scale factor)	TRL 6
78	- rate (gyro scale factor linearity)	TRL 6
79	High-g centrifuge testing provides accelerometer linearity verification up to 200g.	TRL 6
80	Vibration testing provides measures of vibration rectification error (VRE).	TRL 6
81	IMU performance is measured against the HG1730 Critical Item Specification, Document # DS35323-01, dated 2007-12-17.	TRL 6
82	**System Integration Facility (SIF)**	TRL 6
83	SIF testing ensures that IMU interface functionality is maintained as the interceptor components are assembled.	TRL 6
84	SIF testing is top-level and provides only a general check that the IMU is operational, usually via direction cosine matrix (DCM) checks in several orientations.	TRL 6
85	Hardware-in-the-Loop (HWIL)	TRL 6
86	HWIL tests are used to confirm that the IMU mounting orientation is correct by inspection of IMU DCM values, and magnitudes and signs of IMU-reported rates about each missile body axis relative to the applied rates.	TRL 6
87	Flight Tests	
88	**Fire Control**	
89	**Deployment**	TRL 5
90	Slew Rate	TRL 5
91	Elevation Rate	TRL 5
92	Warm up	TRL 5
93	BIT	TRL 5
94	Self Calibration	TRL 5
95	Launch Controller	TRL 5
96	Warhead	TRL 5
97	IMU	TRL 5
98	Fire control	TRL 5
99	**Eject (SE)**	TRL 5
100	Vertical Launch Architecture	TRL 5
101	Eject Gas Generator (EGG)	TRL 5

102	Pop-Up / Pitch-Over (PUPO)	TRL 5
103	POMs (Pitch-Over Motors)	TRL 5
104	**Command and Control Processor**	TRL 5
105	Fuze Board Approval Letter	TRL 5
106	Memory Requirements (ROM)	TRL 5
107	Conforming Electrical Components	TRL 5
108	Software Requirements	TRL 5
109	Environmental	TRL 5
110	Temperature Envelope	TRL 5
111	Temperature Cycling	TRL 5
112	Vibration MIL-STD-810	TRL 5
113	Temperature Limits (SE)	TRL 5
114	Noise Factors (SE)	TRL 5
115	Anticipated environmental limits/qualifications for each LRU (SE)	TRL 5
116	Lightning strike requirements (SE)	TRL 5
117	Convoy limitations (with the same APS systems installed) (SE)	TRL 5
118	EMI/EMC Requirements	TRL 5
119	SIL Processor Validation Testing	TRL 6
120	Environmental Tests	TRL 6
121	**Search Sensor**	
122	EMI/EMC	TRL 5
123	Clutter	TRL 5
124	FOV	TRL 5
125	Resolution	TRL 5
126	Update Rate	TRL 5
127	False Alarm Rate	TRL 5
128	Optical	TRL 5
129	Sensor Architecture	TRL 5
130	Vibration (Microphonics, etc.) (SE)	TRL 5
131	**Tracking Sensor**	
132	EMI/EMC	TRL 5
133	Clutter	TRL 5
134	FOV	TRL 5
135	Resolution	TRL 5
136	Update Rate	TRL 5
137	False Alarm Rate	TRL 5
138	Optical	TRL 5
139	**Sensor Architecture**	TRL 5
140	Vibration (Microphonics, etc.) (SE)	TRL 5
141	Sensor Validation Testing	TRL 6
142	Environmental Tests	TRL 6

143	**Software**	
144	**Software Development Plan**	TRL 5
145	Information Assurance Risks are identified	TRL 4
146	Metrics that will be used during software development are defined (ex. SLOC, Function Points, Requirements Volatility, …)	TRL 4
147	Requirements are configuration managed (through formal CM plan at TRL 5)	TRL 4
148	Security classification of all system data is documented.	TRL 5
149	Software Development Metrics are being collected	TRL 5
150	Configuration Management plan documented	TRL 5
151	Configuration Management plan followed	TRL 5
152	The developer's processes are in compliance with CMMI Level 3 or equivalent	TRL 6
153	Draft software documentation is available (Software Requirements Specification, Software Design Document, …)	TRL 6
154	Developer is able to estimate software program size in lines of code and/or function points	TRL 4
155	Software Development metrics are sufficient to ensure effective process management	TRL 4
156	Software issues are tracked	TRL 5
157	Software issues are configuration managed	TRL 5
158	Software Quality Assurance program is documented	TRL 5
159	Software Quality Assurance program is actively monitoring software development	TRL 5
160	Interface control process is established	TRL 6
161	Software Development Metrics are used to improve process and / or product quality	TRL 6
162	Draft preliminary user manual is available.	TRL 6
163	**Software SIL Requirements**	TRL 5
164	System requirements are decomposed to allocate appropriate software rqts	TRL 4
165	HEMP hardening requirement matches target vehicle specification	TRL 4
166	TEMPEST requirements are identified	TRL 4
167	EMI/EMC requirements are identified	TRL 4
168	Necessary IA Controls have been identified.	TRL 5
169	External interface requirements are documented (source, format, structure, content, and method of support)	TRL 5
170	System requirements are documented.	TRL 4
171	System requirements match user needs in general terms	TRL 4
172	Software requirements allocated among SW modules (requires draft SW architecture)	TRL 4
173	Performance Requirements for target hardware have been identified and documented.	TRL 4

174	Internal interface requirements are documented, including data requirements and formats	TRL 5
175	**Implementation. Includes software design and coding.**	
176	High level System Architecture is documented which includes interfacing systems.	TRL 4
177	Software Architecture development has begun, including consideration of interoperability, reliability, maintainability, extensibility, scalability, and security issues	TRL 4
178	Software architecture is completed and documented	TRL 5
179	Coding of individual functions/modules completed for initial functionality.	TRL 5
180	Target processors have been identified and are readily available in production quantities.	TRL 6
181	Appropriate IA Controls have been implemented in software.	TRL 6
182	All "high severity" software issues have been resolved. "High severity" will vary with the individual issue tracking system, but generally defined as "affects mission with no work-around available".	TRL 6
183	Analysis of timing constraints completed	TRL 6
184	Analysis of database structures and interfaces completed	TRL 6
185	**Demonstration and Validation. Includes all SIL activities.**	
186	Individual functions or modules demonstrated in a laboratory environment (interfaces are emulated/simulated)	TRL 4
187	Some ad hoc integration of functions or modules demonstrates that they will work together	TRL 4
188	End-to-end functionality of the system software is demonstrated in a laboratory environment (simulated interfaces to external systems). APS Example: The system receives a simulated detection from a sensor, performs necessary processing, and activates a simulated countermeasure.	TRL 5
189	Software runs on processor(s) with characteristics representative of target environment	TRL 5
190	Representative model/prototype demonstrated in a high-fidelity lab / simulated operational environment. Includes external interfaces to fielded systems.	TRL 6
191	**SIL Validation Testing**	
192	Stressing Case 1 Complex Attack	TRL 6
193	Stressing Case 2 Clutter	TRL 6
194	Stressing Case 3 Simultaneous Attack	TRL 6
195	**Power Supply**	
196	Environmental	TRL 5
197	Temperature Envelope	TRL 5
198	Temperature Cycling	TRL 5
199	Vibration	TRL 5
200	Safety Board Approval Letter	TRL 6
201	Memory Requirements (ROM)	TRL 5
202	Conforming Electrical Components	TRL 5

203	Software Requirements	TRL 5
204	SMALL ARMS Protection (7.62 Ball)	TRL 5
205	Cyclic Power Testing	TRL 5
206	Environmental Tests	TRL 6
207	**CDA / Controller**	
208	Fuze Board Approval Letter	TRL 6
209	Memory Requirements (ROM)	TRL 5
210	Adjustable Illumination	TRL 5
211	Conforming Electrical Components	TRL 5
212	Environmental	TRL 5
213	Temperature Envelope	TRL 5
214	Temperature Cycling	TRL 5
215	Vibration	TRL 5
216	Environmental Tests	TRL 5
217	System Demonstration	
218	General Test Documentation	TRL 4
219	Document System Configuration (P/N, S/N, and Software Builds)	TRL 5
220	Document all test article and sensor locations and orientations (GPS)	TRL 5
221	Document environmental conditions (temp, wind, humidity).	
222	Take pictures of test articles and test setup	
223	Examine test articles for damage, physical anomalies, and/or missing parts & record observations	
224	Test series will be tailored for vehicle classes	
225	Physical Inspection and Measurement	
226	Visual Inspection	
227	Size and Weight	
228	Function check-out	
229	Emulated Intercept Tests (Rocket-On-Wire or Inert Threat)	TRL 5
230	Single Threat Detection and Tracking	TRL 5
231	Near Simultaneous Engagement Multiple Threats	TRL 6
232	High Angle of Attack	TRL 6
233	Edge of Coverage Envelope	TRL 6
234	Threat Discrimination (7.62mm/40mm Inbound)	TRL 5
235	Threat Discrimination (7.62mm/40mm Outbound)	TRL 5
236	Live Threat Intercept Tests – Stationary Platform	TRL 6
237	Single Threat Engagement	TRL 6
238	Near Simultaneous Engagement Multiple Threats	TRL 6
239	High Angle of Attack	TRL 6
240	Collateral Hazard Characterization Tests	TRL 6
241	Data for hazard analysis collected during other tests	TRL 6
242	**Reliability Testing**	TRL 5

243	TARDEC Validation Testing	TRL 6
244	**Functional Interface Parameters**	
245	**Electronic**	
246	Signal Characteristics	TRL 5
247	Wave Forms	TRL 5
248	Voltage	TRL 5
249	Frequencies	TRL 5
250	Shielding Requirements	TRL 5
251	Circuit impedance	TRL 5
252	Current Limits / requirements	TRL 5
253	**ELECTRICAL**	
254	power requirements	TRL 5
255	Temperature Envelope (SE)	TRL 5
256	Frequency characteristics	TRL 5
257	Temperature Cycling (SE)	TRL 5
258	Voltage levels	TRL 5
259	Sand (SE)	TRL 5
260	Power ratings	TRL 5
261	Humidity (SE)	TRL 5
262	Wave forms	TRL 5
263	Salt Spray (SE)	TRL 5
264	Vibration MIL-STD 810 (SE)	TRL 5
265	Environmental Tests (SE)	TRL 5
266	Grounding requirements	TRL 5
267	**HYDRAULIC AND PNEUMATIC**	
268	Flow rates	TRL 5
269	Fluid temperatures	TRL 5
270	Pressure requirements	TRL 5
271	Power requirements/source	TRL 5
272	OPTICAL/ELECTRO-OPTICAL REQUIREMENTS	TRL 5
273	**HUMAN FACTORS/ENGINEERING**	TRL 6
274	**Integration Requirements**	
275	Interface identification and description	TRL 5
276	Functional interface specification details by parameter	TRL 5
277	Physical interface specification details by parameter	TRL 5
278	Environmental parameter details	TRL 5
279	**PHYSICAL INTERFACE PARAMETERS**	
280	Materials specifications (including dissimilar material requirements).	TRL 5
281	Dimensions and tolerances of mating surface (flanges, bolt holes, mounting plates, etc., with applicable sizes, shapes, and spacing).	TRL 5
282	Weight, balance, and center of gravity.	TRL 5

283	Cabling requirements (connectors, routing, etc).	TRL 5
284	Applied loads.	TRL 5
285	Accessibility (installation and removal clearance).	TRL 5
286	**Sealing requirements, leakage prevention and detection.**	TRL 4
287	Pass Through; Formula's guiding the number of and sizes (cross sectional cable area) of vehicle access holes from the vehicle cabin to the exterior required	TRL 5
288	Anticipated weight per unit length of LRU cable	TRL 5
289	LRU component hardening and anticipated vulnerabilities	TRL 5
290	**Verification of ENVIRONMENTAL AND SAFETY PARAMETERS**	
291	Electromagnetic interfaces, compatibility requirements	TRL 5
292	Vibration envelopes	TRL 5
293	Shock limits	TRL 5
294	Acceleration limits	TRL 5
295	Temperature limits	TRL 5
296	Noise factors	TRL 5
297	Anticipated environmental limits/qualifications for each LRU	TRL 5
298	Lightning strike requirements	TRL 5
299	Convoy limitations (with the same APS systems installed)	TRL 5
300	Gate 4	*
301	Vehicle Demonstrator	
302	Vehicle Integration	
303	System Definition	
304	Preliminary Design	
305	A and B kit Configuration Management	
306	EMI / EMC with GFE	
307	Fabricate and install A kit	
308	Install APS	
309	System Integration and Test	
310	System Validation and Test	
311	Arena Test	
312	EMI/EMC Tests	
313	Vehicle Durability (RAM)	
314	RAM/Durability Tests	
315	Performance Testing	
316	Sensor FOV Validation	
317	Safety Interlocks	
318	Sensor OTM Performance Validation (Clutter, pitch, yaw etc)	
319	Software Validation (Vehicle Coordinates, safety lock outs etc)	

320	SIL Validation	
321	Mobility Analysis	
322	AP limitation on Vehicle Operation	
323	Maintenance / Reloading	
324	Reload Test with Time Analysis and tools required.	
325	**Danger Zone Assessment**	
326	Test	
327	**Radar Safety Assessment**	
328	Test	
329	**Fratricide**	
330	Test	
331	Convoy Operations / limitations (Jamming etc) Analysis	
332	Safety Certification Release / Vehicle	
333	Integrated Performance	
334	Live Threat Intercept Tests – Moving Platform	
335	Single Threat Engagement	
336	**VEHICLE CONFIGURATION SOFTWARE VALIDATION**	
337	Sensor OTM Performance Validation (Clutter, pitch, yaw etc)	
338	Software Validation (Vehicle Coordinates, safety lock outs etc)	
339	SIL Validation	
340	SIL "Components" integrated work together, messages transmitting, protocols established, scenarios running	TRL 4
341	SIL- Concept System Analysis complete Preliminary SWAP-C	TRL 4
342	SIL- Concept System Analysis complete: Analytical Model developed; works in conjunction with SIL. Performance Data, SRL.	TRL 4
343	**System Safety and Integration Parameters**	
344	Description of powered system modes	TRL 4
345	Maintenance considerations	TRL 4
346	Safety lockout considerations	TRL 4
347	Radius of potential injury for surrounding personnel (include the anticipated injury severity).	TRL 5
348	**Operations & Support / Logistic Plan**	
349	LRU Component Maintenance Requirements and Interval	TRL 6
350	LRU Anticipated shelf / useful shelf life	TRL 6
351	Shipping requirements	TRL 5
352	Packaging and Shipping instructions	TRL 6
353	Shipping Container Description	TRL 5
354	Reload Procedure	
355	Remove Misfire CMT	
356	Define CMT disposal method	
357	**Maintenance Plan**	TRL 6

358	Develop Tech Manual	TRL 6
359	Develop Maintenance Tools	TRL 6
360	Training	TRL 6
361	Technical Documentation Release	
362	Material Release	
363	Prototype Demonstration in Relevant Environment	TRL 6
364	ROM Cost Parameters	TRL 5
365	TRL6 Certified with high chance of success	
366	Engineering Prototype LRU cost	TRL 5
367	Gate 5	*
368	Limited Production LRU costs	TRL 5
369	Full Production LRU costs.	TRL 6
370		
371	**Quality Assurance**	TRL 5